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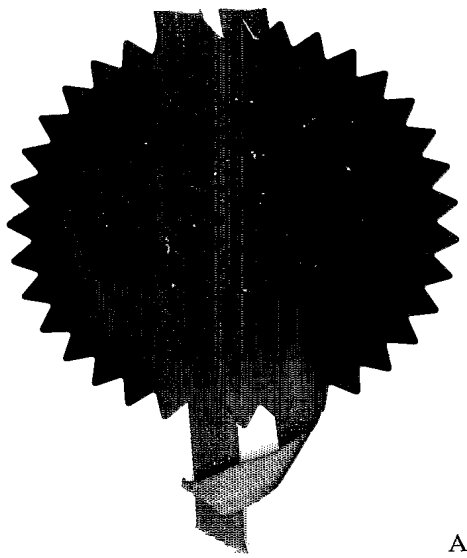

Signed William Morell

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Request for grant of a patent

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2. Application numbe: 0409549.3

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3. Full name, address and postcode of the or each Applicant

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4. Title of the invention: **CURRENT MEASUREMENT APPARATUS**

5. Name of agent: **APPLEYARD LEES**

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Patents ADP number: **190001**

6. Priority claimed to:

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7. Divisional status claimed from:

Number of parent application	Date of filing
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8. Is a statement of inventorship and of right to grant a patent required in support of this application? **YES**

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	
Description	15 (x2)
Claim(s)	
Abstract	
Drawing(s)	4 (x2)

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Priority documents	
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Statement of inventorship and right to grant a patent (PF 7/77)	
Request for a preliminary examination and search (PF 9/77)	
Request for substantive examination (PF 10/77)	
Any other documents (please specify)	

11. We request the grant of a patent on the basis of this application.

Signature Date

APPLEYARD LEES **28 April 2004**

Appleyard Lees

12. Contact **Nicholas Jackson- 01422 330110**

CURRENT MEASUREMENT APPARATUS

Field of the Invention

The present invention relates current measurement apparatus and a method of measuring current and, in particular, pulsed or alternating currents.

Background to the Invention

The Rogowski Coil was invented by Chattock in the 1880's (Chattock A.P. On a magnetic potentiometer Philos Mag., 1887 pp 94-96). It is a flexible solenoid with a co-axial return conductor and is used in non-intrusive manner to sense the magnetic field generated by a current carrying conductor by encircling said conductor. The output of the Rogowski Coil is a voltage proportional to the derivative or rate of change of the current being measured. Means need to be provided to integrate this voltage output to create a voltage output proportional to the current being measured.

Based on Ampere's theorem, if a solenoid of length l having N turns of area A, and a pitch of n= N/l, encircles the current carrying conductor perpendicularly with a radius $R=l/2\pi$ centred around said conductor, the magnetic field B at the centre of each turn is given by $B=\mu_0 i(t)/(2\pi R)$. Provided that $A<<R^2$ the flux per turn is AB(t) which leads to the familiar equation for the output of a Rogowski coil being $e(t) = -Nd(AB(t)/dt = -\mu_0 nAdi(t)/dt$

The Rogowski coil only integrates the rate of change of flux density B correctly if the coil layout is closed. Any deviation from this closed loop results in an incomplete line integral, as defined by Ampere's Theorem, and therefore, a degraded accuracy in measurement of the current.

The present state of the art flexible Rogowski coils tend to use butt joins given the nature of the loop closing coupling designs resulting in erroneous measurements. However, other joint designs are also used e.g., right angle joints and parallel joints. By winding extra turns at the butt joint interface improvements to accuracy are possible.

Industrial International Safety Standards e.g., IEC 61010 prescribe minimum creepage and clearance distances which further exacerbate the situation with regard to measurement performance.

The wire contained in a Rogowski coil is generally provided with an insulated covering or coating. Functional insulation for safety purposes as described in safety standards (e.g. EN61010-1:2001 Clause 6.9.1) state that the following shall not be used as insulation for safety purposes; (1) materials which can be easily damaged (e.g. physically damaged) for example lacquer, enamels, oxides, anodic films, and (2) non-impregnated hygrospic materials (for example paper, fibrous material).

It is an aim of the present invention to overcome at least one problem associated with the prior art whether referred to herein or otherwise.

Summary of the Invention

According to a first aspect of the present invention there is provided current measurement apparatus comprising a Rogowski coil wherein the Rogowski coil comprises a wire which is insulated prior to forming the Rogowski coil.

Preferably the wire is insulated for safety purposes.

Preferably the wire is provided with functional insulation for safety purposes and preferably as described in appropriate safety standards.

Preferably the wire is insulated by insulating material.

Preferably the insulating material cannot be easily damaged and preferably cannot be easily physically damaged.

Preferably the insulating material comprises a resilient material.

Preferably the insulating material comprises a water resistant material.

For safety purposes, the following types of materials may not be considered suitable: a) materials which can be easily damaged (for example, lacquer, enamel, oxides, anodic films etc); b) non-impregnated hygroscopic materials (for example, paper, fibres, fibrous materials etc).

Preferably the complete outer surface of the wire is coated with an insulating material which preferably provides insulation and more preferably reinforced insulation (referred to in this document as insulation). In particular, the outer surface of the wire is insulated and not merely coated.

Preferably the insulating material comprises a wrapping for the wire or an extrusion for the wire. Preferably the insulation material is not applied to the wire (for example as a lacquer would).

Preferably the Rogowski coil comprises a single insulated wire which provides a central conductor and a coil and more preferably comprises a single homogeneous insulated wire which provides a central conductor and a coil.

The insulation coating may be less than 0.25mm and preferably is less than 0.175mm and more preferably is less than or equal to 0.125mm.

Preferably the Rogowski coil is formed by providing a central conductor section and winding a coil around at least a part of the central conductor section. The Rogowski coil may comprise an inner sheath (for example a dielectric sheath) and the inclusion of such a sheath may depend upon the output characteristic requirements of the Rogowski coil.

Preferably the wire comprises copper wire.

Preferably the Rogowski coil comprises an end wherein the end does not require an insulation cap.

Preferably the wire is insulated along substantially the complete length thereof.

The wire may comprise a plurality of layers of insulating material. The wire may comprise two or three or more layers of insulating material.

Preferably the Rogowski coil comprises a first end and a second end. Preferably, in use, the first end is arranged, in use, to locate adjacent to the second end.

Preferably, in use, a first end member located on the first end is arranged, in use, to engage a second end member located on the second end of the Rogowski coil.

Preferably a first end member located on a first end of the Rogowski coil is arranged, in use, to cooperate with a second end member located on a second end of the Rogowski coil.

Preferably, in use, a first end member on a first end of the Rogowski coil is arranged, in use, to locate (or cooperate or engage) a second end member located on a second end of the Rogowski coil in order to form a substantially contiguous loop or circle.

Preferably a first end of the Rogowski coil is arranged to magnetically cooperate with the second end of the Rogowski coil and preferably to form a contiguous loop or circle.

Preferably a first end member locates on or towards a first end of the Rogowski coil and a second end member may locate on or towards a second end of the Rogowski coil.

The first end member may comprise a female member and the second end member may comprise a male member. Preferably at least a part of the male member is arranged, in use, to locate in a part of the female member.

The first end member may comprise a magnetic member. The first end member may comprise a ferromagnetic material.

The second end member may comprise a magnetic member. The second end member may comprise a ferromagnetic material.

The second end member may comprise a metal.

The second end member may comprise a plate or planar member.

Preferably the first end member is arranged, in use, to be secured to the second end member solely by magnetic force.

According to a second aspect of the present invention there is provided a method of forming current measurement apparatus comprising forming a Rogowski coil from an insulated wire.

The method may comprise forming a central conductor section and forming a coil around the central conductor section using insulated wire.

According to a third aspect of the present invention there is provided a method of measuring current comprising using current measurement apparatus in accordance with the first aspect of the present invention.

According to a fourth aspect of the present invention there is provided a method of measuring current comprising using current measurement apparatus formed in accordance with the third aspect of the present invention.

According to a fifth aspect of the present invention there is provided current measurement apparatus comprising a Rogowski coil wherein the Rogowski coil comprises a first end and a second end and, in which, in use, the first end is arranged, in use, to be secured to the second end by magnetic means.

Preferably, in use, the first end is arranged, in use, to locate adjacent to the second end. Preferably, in use, a first end member located on the first end is arranged, in use, to engage a second end member located on the second end of the Rogowski coil.

Preferably a first end member located on a first end of the Rogowski coil is arranged, in use, to cooperate with a second end member located on a second end of the Rogowski coil.

Preferably, in use, a first end of the Rogowski coil is arranged, in use, to locate (or cooperate or engage) a second end member located on a second end of the Rogowski coil in order to form a substantially contiguous loop or circle.

Preferably a first end of the Rogowski coil is arranged to magnetically cooperate with the second end of the Rogowski coil and preferably to form a contiguous loop or circle.

Preferably a first end member locates on or towards a first end of the Rogowski coil and a second end member may locate on or towards a second end of the Rogowski coil.

The first end member may comprise a female member and the second end member may comprise a male member. Preferably at least a part of the male member is arranged, in use, to locate in a part of the female member.

The first end member may comprise a magnetic member. The first end member may comprise a ferromagnetic material.

The second end member may comprise a magnetic member. The second end member may comprise a ferromagnetic material.

The second end member may comprise a metal.

The second end member may comprise a plate or planar member.

Preferably the first end member is arranged, in use, to be secured to the second end member solely by magnetic force.

Brief Description of the Drawings

The present invention will now be described, by way of example only, with reference to the drawings that follow, in which:

Figure 1 is a perspective view of part of a prior art Rogowski coil.

Figure 2 is a perspective view of part of an end of a prior art Rogowski coil including an end cap.

Figure 3 is a perspective view of part of a preferred embodiment of a Rogowski coil in accordance with the present invention.

Figure 4 is a perspective view of part of a preferred embodiment of an insulated wire for use in a preferred embodiment of a Rogowski coil.

Figure 5 is a perspective view of a preferred embodiment of a Rogowski coil, in use.

Figure 6 is a side cross-section of a first end and a second end of a prior art Rogowski coil.

Figure 7 is a side view of a preferred embodiment of a first end and a second end of a Rogowski coil, prior to use.

Figure 8 is a side view of a preferred embodiment of a first end and a second end of a Rogowski coil, in use.

Description of the Preferred Embodiment

As shown in Figure 3, a preferred embodiment of electric current measurement apparatus comprises a Rogowski coil 20 comprising a wire or conductor which forms a coil 22 and

returns through the coil 22 as a central conductor 24. The coil 22 and the central conductor 24 are formed from a single conductor or wire and, therefore, no electrical join (for example, a solder join or crimp) is required at the end of the Rogowski coil 20. Such joints are required in prior art Rogowski coils.

The wire 28 used to form the coil 22 and the central conductor 24 is insulated prior to forming the Rogowski coil 20, as shown in Figure 4. The wire 28 is coated with the required amount of insulation 30 or insulation material. The wire 28 is not merely coated with a coating material since this would not provide the necessary insulation characteristics. The insulated coating 30 on the wire 28 provides better insulation between individual coils and also helps provide a more even spacing between coils relative to providing insulating sheaths or sleeves. The wire 28 is copper and the outer surface thereof is completely coated along the length thereof. However, the end of the wire 28 enable the wire to be electrically connected to measurement apparatus to measure the induced current in the Rogowski coil 20 and, therefore, to calculate the electrical current in a conductor 32.

The wire is covered with a functional insulation material for safety purposes as described in safety standards (for example EN 61010-1:2001 Clause 6.9.1). Such standards exclude the following for use as insulation for safety purposes; (1) materials which can be easily damaged (for example, lacquer, enamels, oxides, anodic films), and (2) non-impregnated hygroscopic materials (for example, paper fibrous material). Accordingly, the insulating material comprises a resilient material to prevent or at least

inhibit physical damage thereof. In addition, the insulation material comprises a water resistant material.

The wire is coated or covered by a plurality of layers of insulating material 30 and in the preferred embodiment comprises triple insulated material having three concentric layers of insulating material around the wire 28. In particular, the insulating material 30 of the present invention is wrapped or extruded rather than applied as a lacquer would.

The coil end would only require protection from physical abuse and/or damage. The coil end of prior art Rogowski coils require an insulation cap 11 to further insulate the end of the Rogowski coil as shown in Figure 1 and Figure 2.

The coil 22 and central conductor 24 of the present invention have a natural electrical safety barrier built into the construction. In addition, in a coil formed using the pre-insulated wire there would be no other requirement for protection other than for physical abuse and/or damage.

The preferred embodiment provides 600V rating with triple insulated wire. The insulation coating 30 of the copper wire 28 is substantially equal to or less than 0.125mm. That is the radial thickness of the insulation is equal to or less than 0.125mm. For higher voltages, the insulation coating may be thicker. The dielectric breakdown voltage would be greater than 1kV or as appropriate for the voltage ratio required.

Since the wire forming the coil 22 and (straight) central conductor section 24 is pre-insulated the physical dimension of the Rogowski coil are minimised and also an end cap to provide insulation is not required. Prior art Rogowski coils are relatively bulky since they include an inner dielectric sheath 12 and an outer sheath 14 or jacket that is thick enough to provide for electrical safety and physical abuse. In use, the Rogowski coil 20 is located around an electrical conductor 32 in order for the Rogowski coil to measure be current in the electrical conductor 32, as shown in Figure 5.

The present invention results in the Rogowski coil being smaller, better insulated and does not require an end insulting cap for intrinsic safety.

The present invention may include an inner dielectric sheath and the use of such a sheath may provide better insulation. The use of such a sheath may depend upon the output characteristics of the Rogowski coil.

As previously explained (and as shown in Figure 5) the Rogowski coil 20 is formed into a contiguous loop or circle and extends (preferably substantially concentrically) around an electrical conductor 32 in order to measure the current therein. It is generally preferred that the electrical conductor 32 is not interrupted or broken in order for the Rogowski coil 20 to locate therearound and, therefore, the Rogowski coil 20 comprises a first end 42 and a second end 44 which are separable and movable relative to each other but are arranged, in use, to locate adjacent to each other to form a coupling or join 40 therebetween. The ends 42, 44 may be urged

towards each other, in use, for example by resilient means. In particular embodiments the ends are bias towards each other. In use, the first end 42 is moved relative away from the second end 44 in order for the electrical conductor 32 to enter a central region 46 of the Rogowski coil 20. The ends 42,44 of the Rogowski coil 20 can then be moved to locate adjacent to each other. For Rogowski coils 20, it is preferred to have as small gap as possible or separation distance between the ends of the wire at the two ends 42,44 of the Rogowski coil 20. Since the present invention does not require an end cap as used with prior art Rogowski coils then this reduces the distance between the two ends 42,44 of the Rogowski coil 20, in use.

In prior art Rogowski coils, the two ends of the Rogowski coil are connected to each other using a butt join (as shown in Figure 6). In such a joint, a male member 52 is inserted and engaged with a female member 50 in order for the Rogowski coil to form a contiguous loop. However, this requires apparatus that is relatively bulky and which results in an increased separation between the ends of the Rogowski coil and means that such Rogowski coils are not as effective for use with relatively small conductors or in confined areas.

The preferred embodiment of the present invention provides magnetic means in order for the first end 42 of a Rogowski coil 20 to cooperate with the second end 44 of the Rogowski coil 20, as shown in Figure 7 and Figure 8. In particular, the connection is solely made by a magnetic force between the first end 42 and the second end 44.

The first end 42 of the Rogowski coil 20 comprises a first end member 43 and similarly the second end 44 of the Rogowski coil comprises a second end member 45. The first end member 43 comprises a female member comprising a magnet and the second end member 45 comprises a male member comprises a metal plate in particular a ferromagnetic plate. Accordingly, in use, the second end member 45 is attracted and engaged to the first end member 43 to produce and form a contiguous loop around the electrical conductor 32. Since the wire in the Rogowski coil comprises a preinsulated wire there is no requirement for bulky insulating endcaps and the dimensions of the coil itself are also relatively small and therefore the present invention provides a safe, efficient and small means for measuring current in an electrical conductor 32.

Attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

Each feature disclosed in this specification (including any accompanying claims, abstract and drawings) may be replaced by alternative features serving the same,

equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

The invention is not restricted to the details of the foregoing embodiment(s). The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

Fig 1

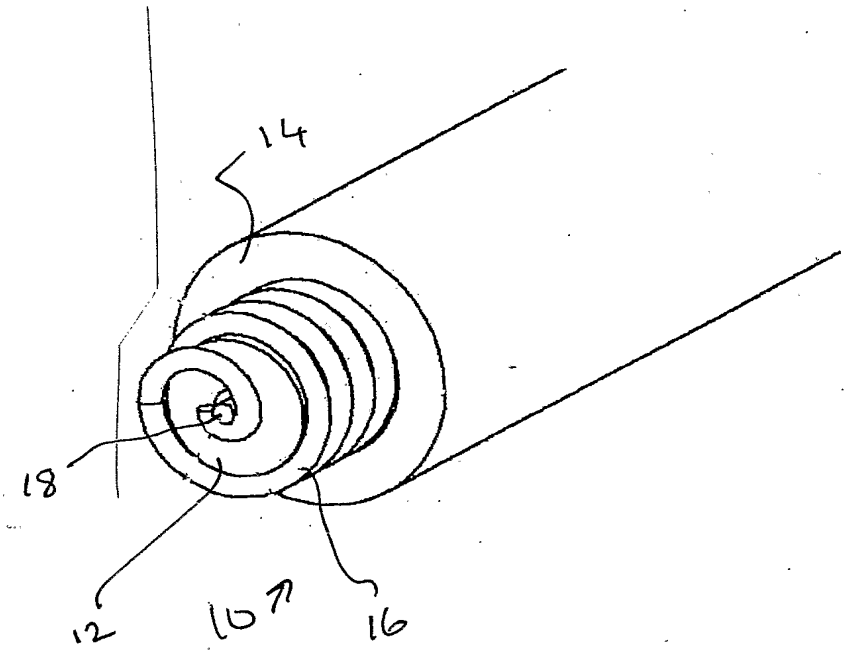
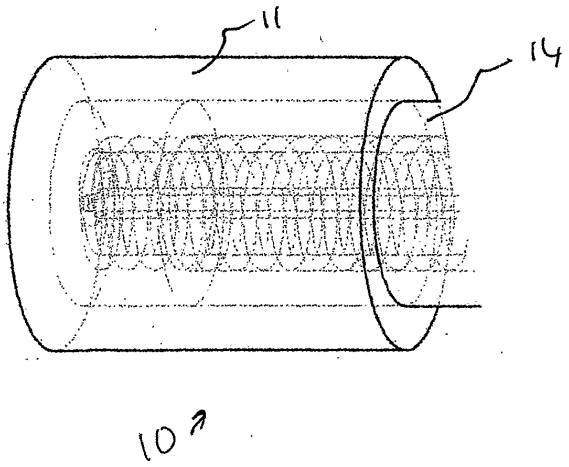


Fig 2.



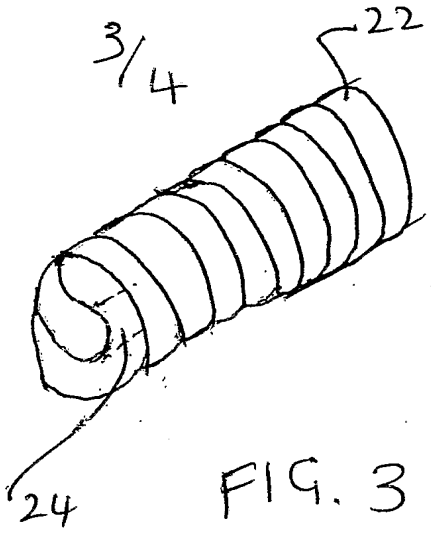


FIG. 3

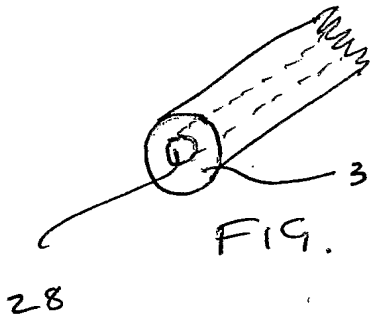


FIG. 4

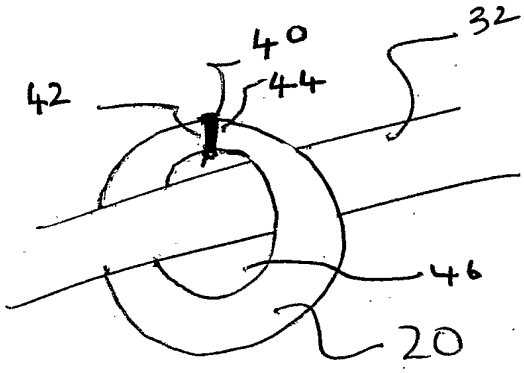


FIG. 5

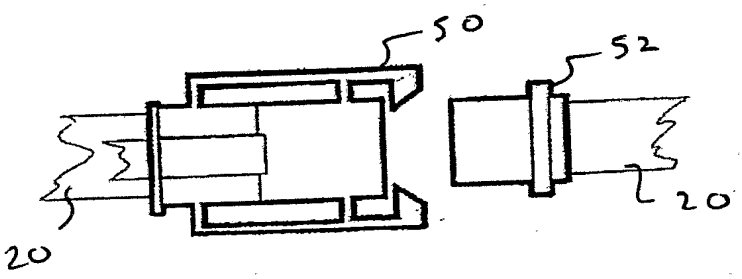


FIG. 6

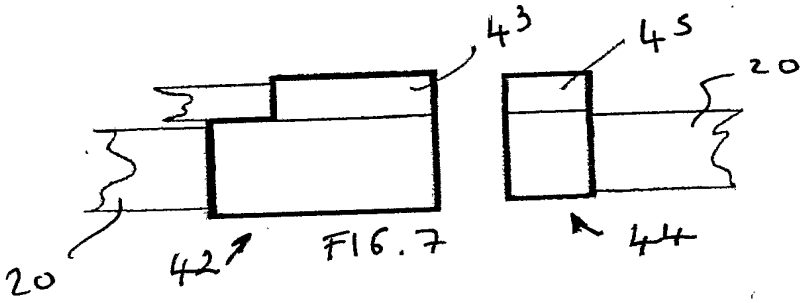


FIG. 7

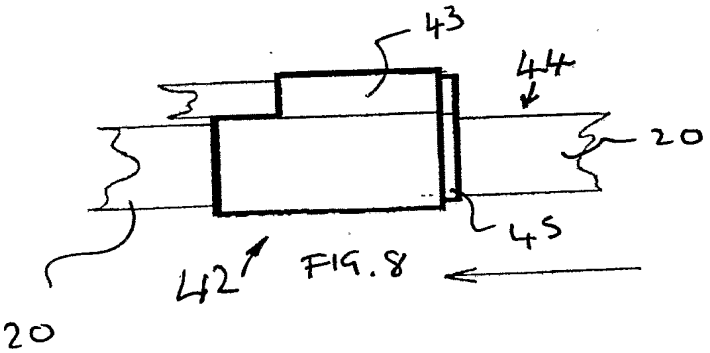


FIG. 8